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AIR FORCE HUMAN RESOURCES LABORATORY

G-SEAT COMPONENT DEVELOPMENT

By

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Wright-Patterson Air Force Base, Ohio 45433

June 1978
Final Report for Period 1 July 1975 – 30 March 1977

AIR FORCE SYSTEMS COMMAND
BROOKS AIR FORCE BASE, TEXAS 78235

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This final report was submitted by Advanced Systems Division, Air Force Human Resources Laboratory, Wright-Patterson Air Force Base, Ohio 45433, under project 6114, with HQ Air Force Human Resources Laboratory (AFSC), Brooks Air Force Base, Texas 78235. Mr. William B. Albery, Simulation Techniques Branch, was the principal investigator.

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An effort was conducted to investigate the improved performance of a closed-loop G-seat system. The Air Force and Navy are currently using G-seats in several training and fighter simulators. These devices are all open-loop systems and exhibit excessive time delays. While these seats exhibit good sustained cueing capability, their performance is marginal in producing overall acceleration cues. Because of sluggish response characteristics, virtually none of the seats can give appropriate acceleration onset cues and be in synchronization with current visual systems. Conventional G-seat components were obtained as well as advanced, position feedback metal bellows, and a closed-loop pneumatic control system was designed and developed. The open- and closed-loop performance of this system was evaluated and the contribution of each component in the G-seat hardware was analyzed. Transfer functions were developed for the pneumatic control system.

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SUMMARY

Problem

The Air Force's first generation G-seat, currently installed in four separate training/research simulators employs an open-loop pneumatic control system. Because of relatively low bandwidth servo control valves and long hose lengths, some of these systems have excessive time delays. While these seats exhibit good sustained cueing capability, their performance is marginal for producing overall acceleration cues. Because of sluggish response characteristics, virtually none of the seats could give appropriate acceleration onset cues and be in synchronization with current visual systems.

One complete channel of G-seat hardware, the servo valve, tubing, pneumatic booster relay, and metal air bellows was evaluated. By employing position feedback in the metal air bellows and lead-lag compensation circuitry in the pneumatic control loop, the performance of the system was improved. Electro-pneumatic transducers (CONOFLOW valves), pneumatic booster relays, plastic tubing, needle valves, and metal air bellows like those utilized in the Air Force's six G-seats were evaluated. A special potentiometer feedback/metal air bellows assembly was evaluated for improved performance. Compensation circuitry was optimized for closed-loop control of the valve-bellows system.

Results

The valve-bellows assembly was evaluated in both the open- and closed-loop configuration. In the open-loop configuration, the valve-bellows arrangement closely matched the G-seat hardware in the Air Force's current G-seat systems.

In the open-loop configuration, the pneumatic system acts like a low-pass filter. Although the pneumatic booster relay improved the rise time and fall time of the metal bellows, it did not improve the initial response time of the system. In the open-loop configuration, the optimum arrangement included a needle valve (between the electro-pneumatic transducer and the bellows) which was bled to the atmosphere. The booster relay was removed. With the needle valve in the system, the initial response time improved from 140ms to 90ms and the fall time improved commensurately; the rise time, however, was not as good as with the booster relay in the system.

The position feedback bellows-valve configuration resulted in the output voltage leading the input voltage at low frequencies and the magnitude response resulting in a band-pass filter with a low resonant frequency. Negative feedback with both lead and lag compensation improved the response of the closed-loop system. In general, the closed-loop system responded 20% faster with a ten times faster rise time for a step input and 30% faster with almost one and one-half times faster ramp rise time for a ramp input.

The effect of hose length between the bellows and valve was also evaluated with the finding that a 15-foot hose resulted in a 35ms lag and a 43-foot hose in a 75ms lag.

Conclusions

An improved pneumatic control system for the G-seat has been demonstrated. In its present open-loop configuration, the Air Force's G-seat performance can be improved by (a) minimizing the hose length between the control valve and bellows and (b) bleeding to atmosphere some of the supply and exhaust air between the valve and bellows. A closed-loop, position feedback bellows was evaluated in a pneumatic control system like that presently in the Air Force's G-seats. The closed-loop system demonstrated an improved performance over the open-loop system.

The position feedback technique is only one of many ways to improve the performance of the G-seat system. It is anticipated that the work described in this report will foster an interest in further developing responsive pneumatic control systems for G-seats.

PREFACE

This study was initiated by the Advanced Systems Division, Air Force Human Resources Laboratory (AFHRL), Wright-Patterson AFB, Ohio, under project 6114, Simulation Techniques for Air Force Training; task 611419, Motion and Force Simulation. Ms. Patricia Knoop was the project scientist. The research was performed at the Advanced Systems Division with Mr. William B. Albery as principal investigator. Mr. Erick D. Hunter performed the evaluation and analysis of the hardware described in this report. The effort was conducted during the period from 1 July 1975 to 30 March 1977.

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G-SEAT COMPONENT DEVELOPMENT

I. INTRODUCTION

The G-seat has become an important part of the total military flying training simulation environment. Recent Air Force and Navy simulator procurements have specified the G-seat as part of the training system. The G-seat is that special device which replaces the pilot's seat in a flying training simulator and by virtue of its geometry and drive philosophy, stimulates principally the tactile and pressure receptors of the pilot's back, buttocks, and thighs. The concept of a G-seat is not new (Johnson, 1958). Recently, the Air Force has renewed the interest in these devices with the development of the G-seats for the Advanced Simulator for Pilot Training (ASPT) and the Simulator for Air-to-Air Combat (SAAC). Favorable comments have been received on the utility of these G-seats (Stark, 1976; Waters & Grunzke, 1976), although some limitations have been identified with respect to their performance (Gum & Albery, 1977).

The Air Force currently owns six (6) G-seats and is in the process of procuring sixteen (16) additional G-seats for retrofitting into F-4E trainers. The six G-seats are located in three simulator facilities. Two of the seats are in the ASPT at Williams AFB, Arizona; two are in the SAAC at Luke AFB, Arizona; one G-seat was in the F-4E Weapon Systems Training Set (WSTS) #18 at Luke AFB, Arizona, but has recently been sent to Williams AFB, Arizona; and the sixth seat is at the NASA/Ames Research Center, Moffett Field, California. This sixth G-seat was fabricated by ASD/ENET, Wright-Patterson AFB, Ohio, at Wright-Patterson, and then delivered to NASA/Ames where it is undergoing evaluation. The sixteen G-seats currently being procured for F-4E trainers will also include a G-suit and seat shaker.

Five of the six G-seat systems have been operational since early 1975; the Ames G-seat has been operational since 1976 and has been used in a KC-135 motion study (MacFarland, Griffin, & DeBerg, 1976) on the Flight Simulator for Advanced Aircraft (FSAA) and is currently installed in the Ames SO-1, a six-degree-of-freedom research simulator.

All six of these G-seats, in addition to the sixteen under procurement, have three common properties which are the subject of this report: (a) they are open-loop pneumatic systems, (b) they are all patterned after the ASPT seat which was designed for research applications with much built-in flexibility, and (c) they are relatively sluggish with respect to response.

II. OBJECTIVE

The objective of this study was to investigate and to improve the engineering performance characteristics of the ASPT-type pneumatic G-seat. The ASPT G-seats (Figure 1) are for the T-37B aircraft simulation whereas the other five seats (and subsequently, the sixteen follow-on systems) are for the F-4E aircraft trainers. The ASPT seat differs from the others in the number of seat pan cells (16 for ASPT, 14 for F-4E seats) and in the backrest drive software. In most other respects, the seats are identical in that they employ the same pneumatic control valves, metal air bellows, and drive philosophies. The ASPT G-seat development has been documented (Kron, 1975).

III. APPROACH

The approach taken to meet the objective of improving the performance characteristics of the pneumatic G-seat was first a component-by-component evaluation. The key elements of the G-seat control loop were isolated and evaluated individually for their contributions to the overall performance. These elements include (a) the electro-pneumatic transducer, or CONOFLOW valve (Figure 2), (b) the metal air bellows (Figure 3), and (c) the booster relays and flexible tubing.

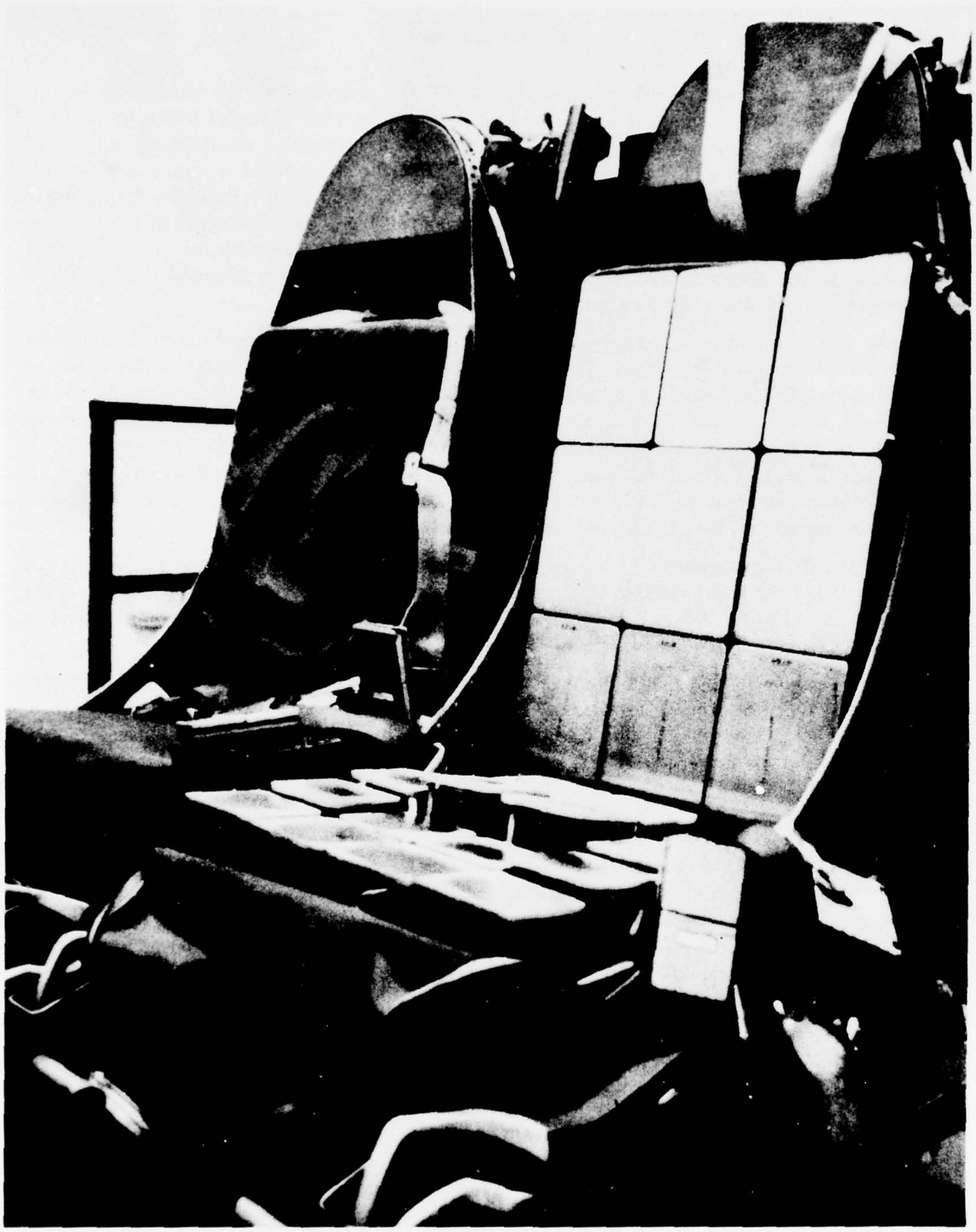


Figure 1. **ASPT G-seat, uncovered.**

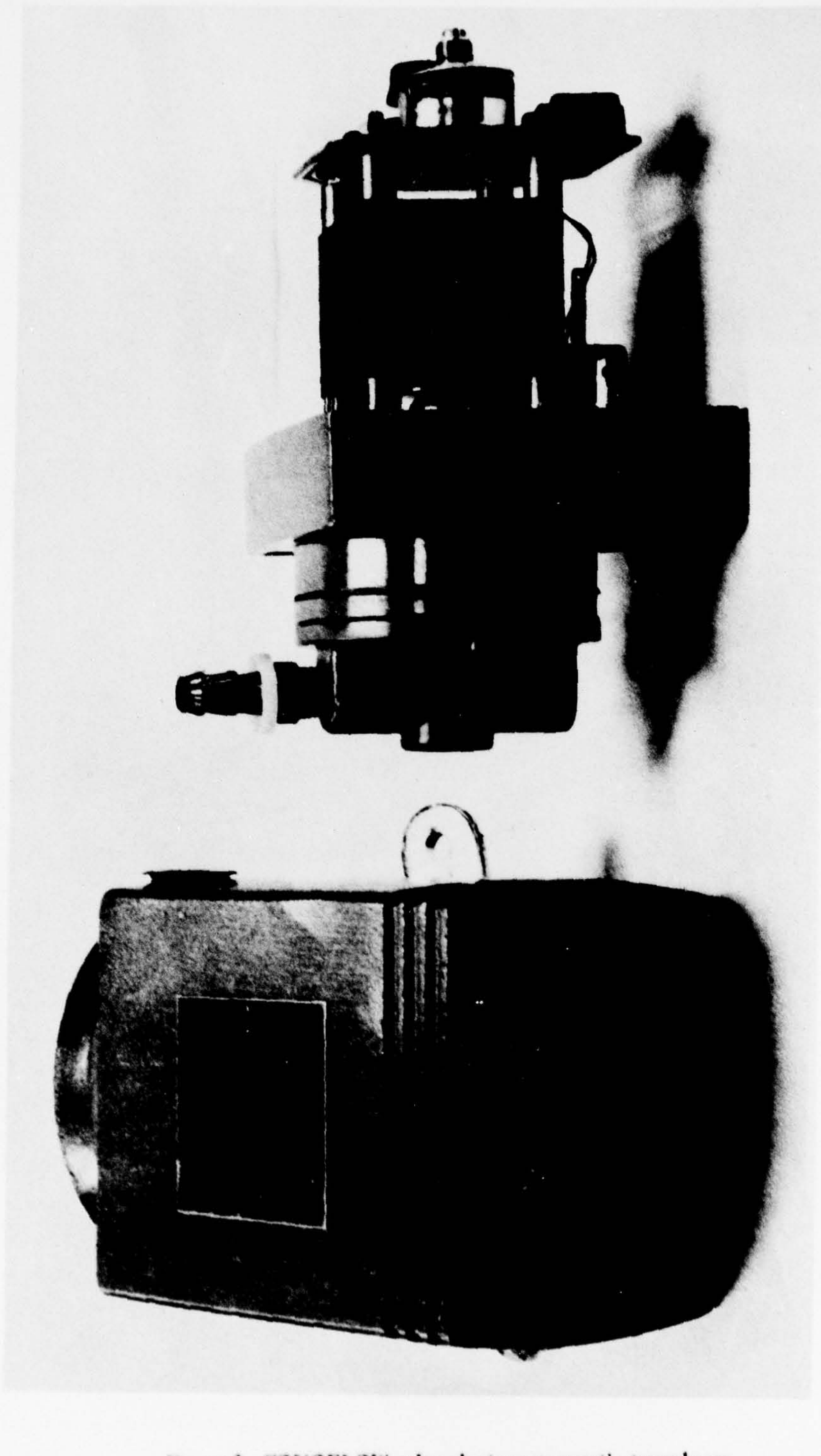


Figure 2. **CONOFLOW valve electro-pneumatic transducer.**

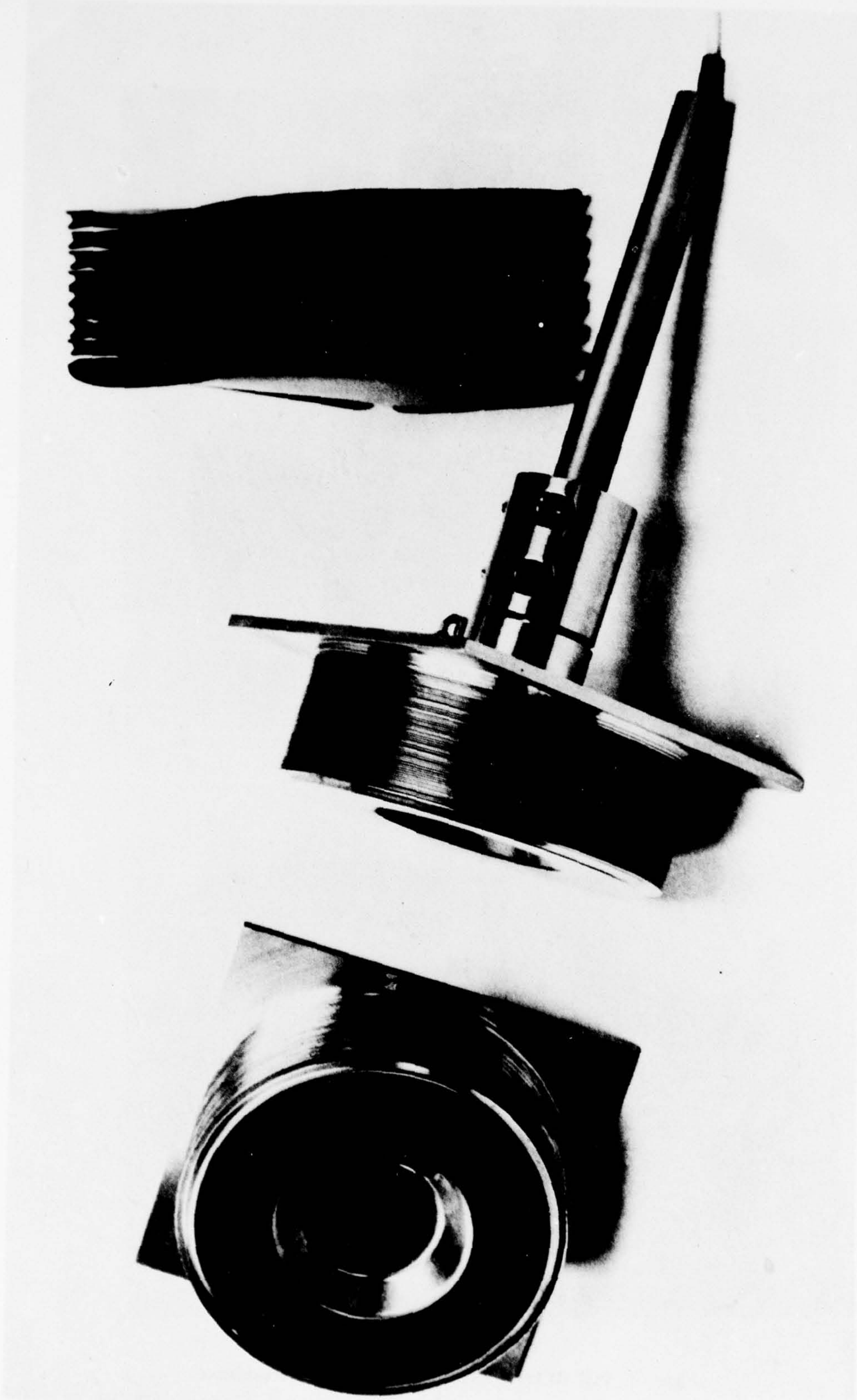


Figure 3. Experimental G-seat bellows; position feedback bellows (center).

A CONOFLOW valve, booster relay, and flexible tubing, like those used in the current G-seats were obtained. In lieu of the conventional metal air bellows (Figure 4), a special metal bellows with a potentiometer imbedded (Figure 3) was developed. The position feedback bellows was then evaluated in conjunction with the CONOFLOW valve, booster relay, varying lengths of tubing, and lead/lag compensation circuitry.

IV. DISCUSSION OF WORK PERFORMED

Each component in the G-seat control system was evaluated and a mathematical analysis of the open- and closed-loop system was performed. The first component evaluated was the CONOFLOW valve.

The CONOFLOW valve, or electropneumatic transducer (Figure 2), is a force-balance device which converts an electrical signal into a corresponding pneumatic pressure. This transducer is an off-the-shelf item which is designed for commercial purposes and not for G-seats. The CONOFLOW valve uses a regulated, 25 psi, dry air source and outputs 0–15 psi depending on the electrical output signal.

The current that flows through a 445 mH coil sets up a magnetic field which pushes the coil out of a permanent magnetic core (Figure 5). A lever, which is positioned over an exhaust nozzle, is attached to this moving inductor. When the coil moves out of the core, the lever moves toward the nozzle and the rate of exhausting air decreases. The exhausting air causes a difference in pressure between the two chambers. Two diaphragms which separate these two chambers distend and push a pneumatic valve open. The opening of this valve causes an output pressure which is approximately linear with respect to the input current through the inductor (Kron, 1975).

The position feedback metal bellows (Figure 6) is a pressure-actuated device. The main body of the bellows is the capsule which consists of stainless steel washers welded together to form a convoluted cylinder. The spring constant of the bellows is proportional to the number of convolutions. This experimental metal bellows has a spring constant of approximately 5 lbs/in. The metal bellows used in the current G-seats have a spring constant of approximately 12 lbs/in. The smaller spring constant for the experimental bellows was chosen for two reasons: (a) since feedback would be employed for control of the bellows, a higher spring constant did not have to be relied on for better position control, and (b) the smaller spring constant bellows should display longer life since it has more convolutions than the conventional bellows.

The bellows has one pneumatic port which is both a filling port as well as a venting port. When pressurized, the bellows has an upward stroke; when depressurized, the bellows has a downward stroke. The wiper arm of a 10,000-ohm linear potentiometer follows the excursion of the bellows faceplate. The bellows and potentiometer coupled together constitute a pneumatic-to-electrical transducer. The CONOFLOW valve and the bellows (pneumatic-to-electrical transducer) can be lumped together to form a voltage transfer function, V_{out} (bellows)/V_{in} (valve). This transfer function was determined experimentally for a closed-loop system analysis.

Three experimental conditions of transient behavior were analyzed in the open-loop system to determine which method was the most promising to improve the response of the overall system. All methods were evaluated for the inflation and deflation cycles and employed 43 feet of tubing connected between the CONOFLOW valve and the bellows. A 10-pound weight was used as a bellows load and both a "positive-going" and "negative-going" step input were applied to the valve. The output response for each case was recorded.

The first setup was simply a CONOFLOW valve and the bellows connected with 43 feet of tubing. The second setup utilized in addition a one-to-one pneumatic booster relay, which is an off-the-shelf item used on the ASPT G-seat and connected between the valve and bellows.

The booster relay was added to the ASPT G-seats to insure rapid exhaust cycle time and to dampen pressure oscillations (Kron, 1975). The booster relay also uses a 25-psi air supply. The third setup utilized a

Figure 4. **ASPT seat pan metal air bellows, fully expanded.**

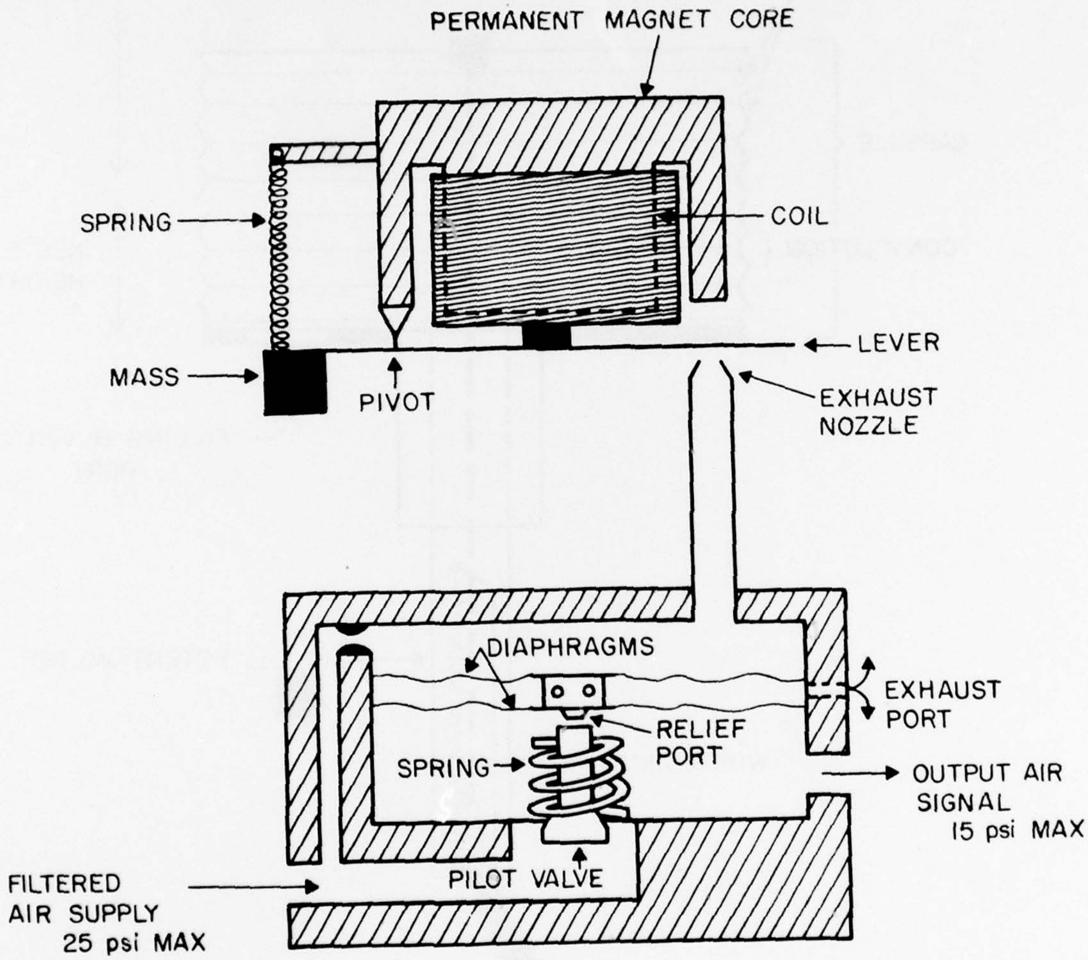


Figure 5. **Schematic of CONOFLOW valve electro-pneumatic transducer.**

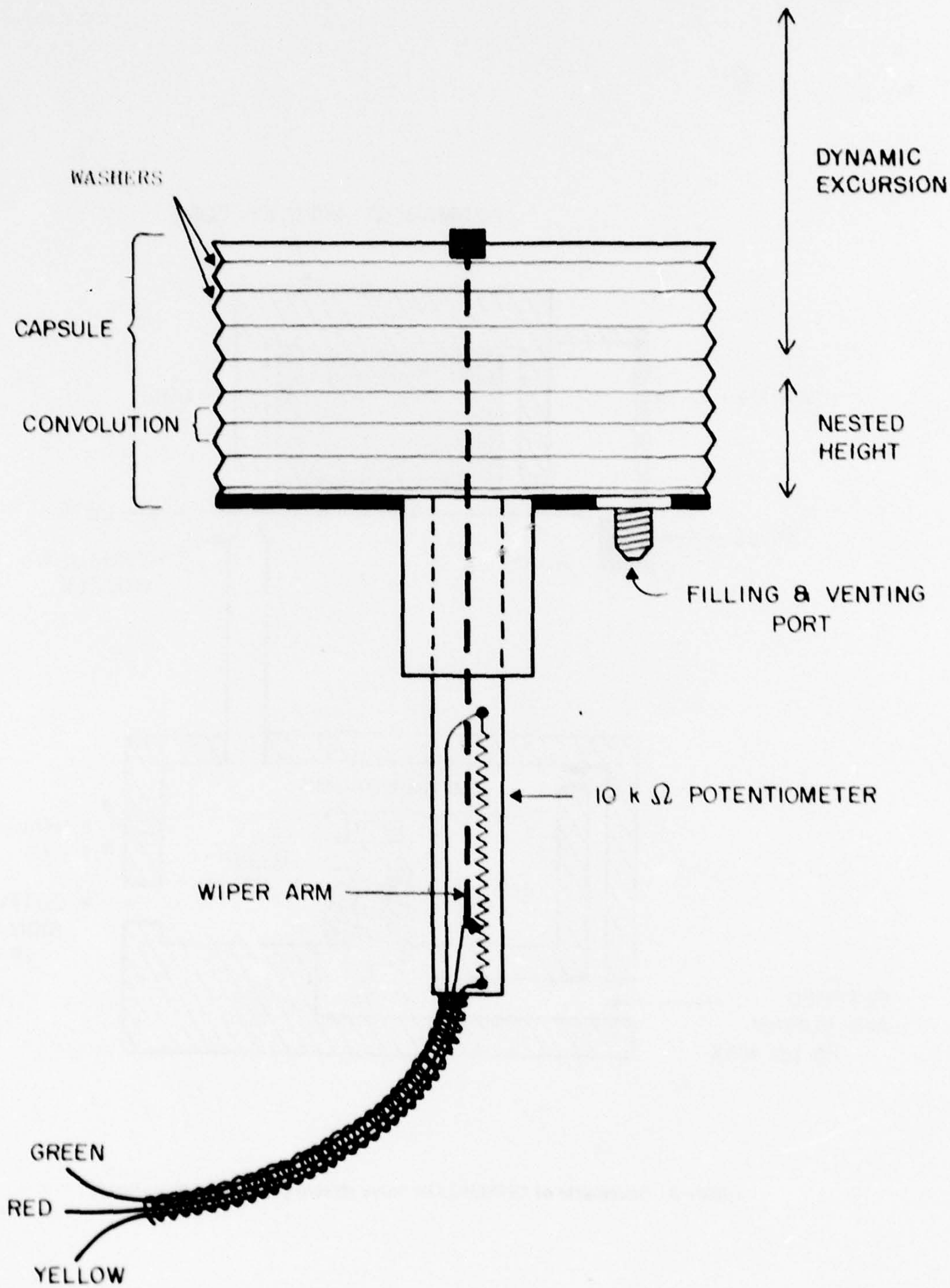


Figure 6. **Schematic of experimental position feedback metal air bellows.**

needle valve located between the CONOFLOW and the bellows to continuously bleed some of the air supplied to the bellows. Output response data for each of the three experimental conditions are recorded in Table 1 and Figure 7.

Table 1. **Open-Loop Transducer Bellows Response Step Input, 43 foot Hose, 10-pound Weight**

Device Connected Between Valve and Bellows	Transport Lag (ms) t_{lag}	Rise Time (ms) t_r	Fall Time (ms) t_f
Booster Relay	140	310	900
Without Booster Relay	140	630	1220
Bleed Valve	90	770	610

Unloaded steady-state system response data were recorded with a sinusoidal input from .01 Hz to 20 Hz; however, the system response was rather nonlinear. A needle valve similar to that used on the ASPT G-seats was installed at the end of the 43 foot, 3/8 inch inner diameter plastic hose between the CONOFLOW valve and bellows. By adjusting the amount of bleed, nonlinearities were alleviated. In addition, greater amplitudes of signal and smaller phase lags were observed (Figure 8). Steady-state amplitude and phase data were recorded by frequency sweeping the open-loop system with a sinusoidal input signal. Frequency response plots were constructed (Figures 9 and 10). Also transient behavior of the system was recorded for a step input (Figure 11).

With these two methods, steady-state and transient analysis, an approximate voltage transfer function of the CONOFLOW valve-bellows system was formulated.

$$G(s) = \frac{9e^{-.070s}}{\left(\frac{S}{1.4}+1\right)\left(\frac{S}{14}+1\right)\left(\frac{S}{22}+1\right)} \qquad (1)$$

The e^{-Ts} term is transport lag which contributes only to phase lag since its magnitude is unity at all frequencies. The initial response or transport lag is caused primarily by the compressibility of the air and possibly by the modulation of the inner walls of the tubing. This time delay can be reduced by minimizing the hose length between the bellows and CONOFLOW valve.

The three factors in the denominator of equation 1 are the poles of the system. They cause the high frequency roll-off. The entire system essentially acts like a low-pass filter in an open-loop configuration.

With this approximate model a feedback configuration was designed to improve phase response (Figure 12). The design configuration shown has the following open-loop gain equation:

$$G(s)H(s) = \frac{18e^{-.070s}\left(\frac{s}{2}+1\right)}{\left(\frac{s}{.1}+1\right)\left(\frac{s}{4.4}+1\right)\left(\frac{s}{44}+1\right)\left(\frac{s}{69}+1\right)} \qquad (2)$$

where G(s) is the transfer function of the valve-bellows system (Equation 1) and H(s) is the transfer function of the lead-lag compensation:

$$H(s) = \frac{\frac{(R2)}{(R1)}\,\frac{(R4)}{(R3)}\,(s\,R_3\,C_2+1)}{(s\,R_3\,C_1+1)} \qquad (3)$$

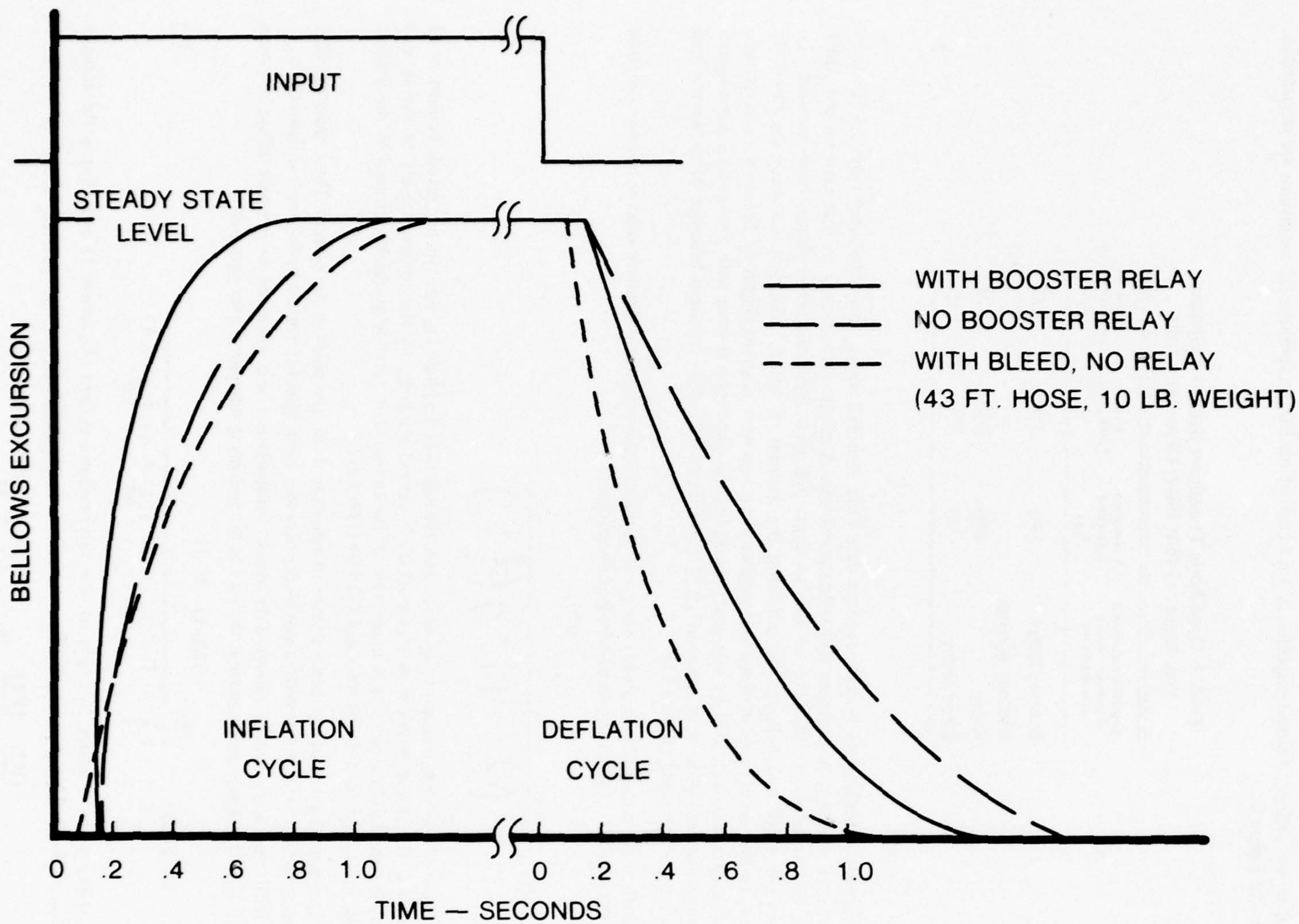
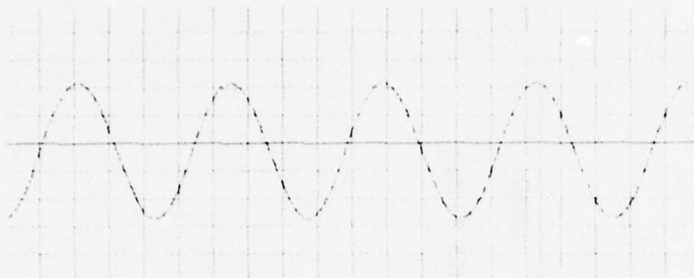
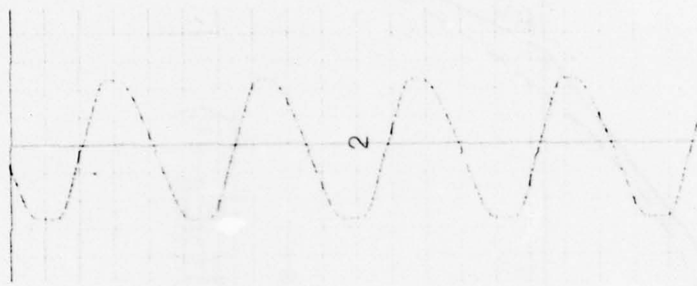


Figure 7. **Open-loop performance of bellows to step input.**



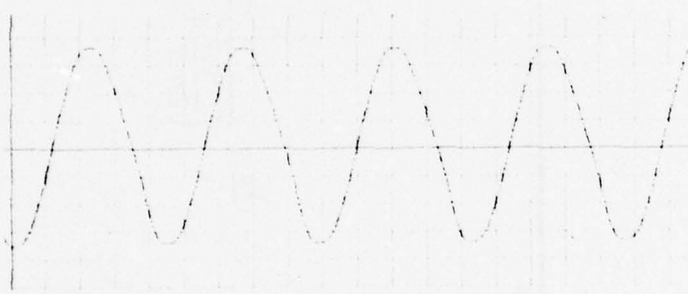
Sinusoidal Input Signal

(1 Hz)



Output Signal Without Bleed

(330ms Phase Lag)



Output Signal With Bleed

(240ms Phase Lag)

Figure 8. **Effect of needle valve bleed on bellows response.**

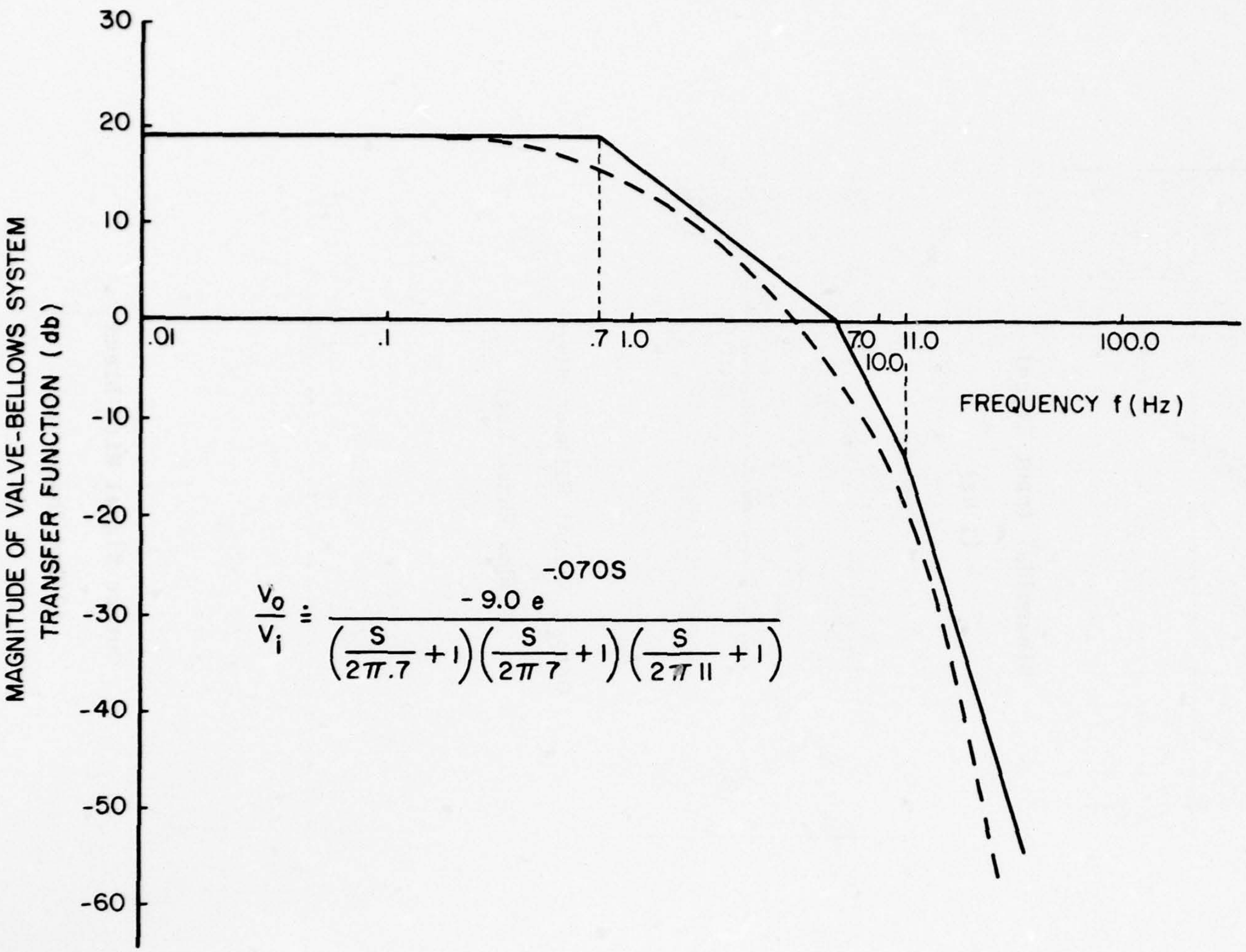


Figure 9. **Magnitude response of open-loop valve-bellows system.**

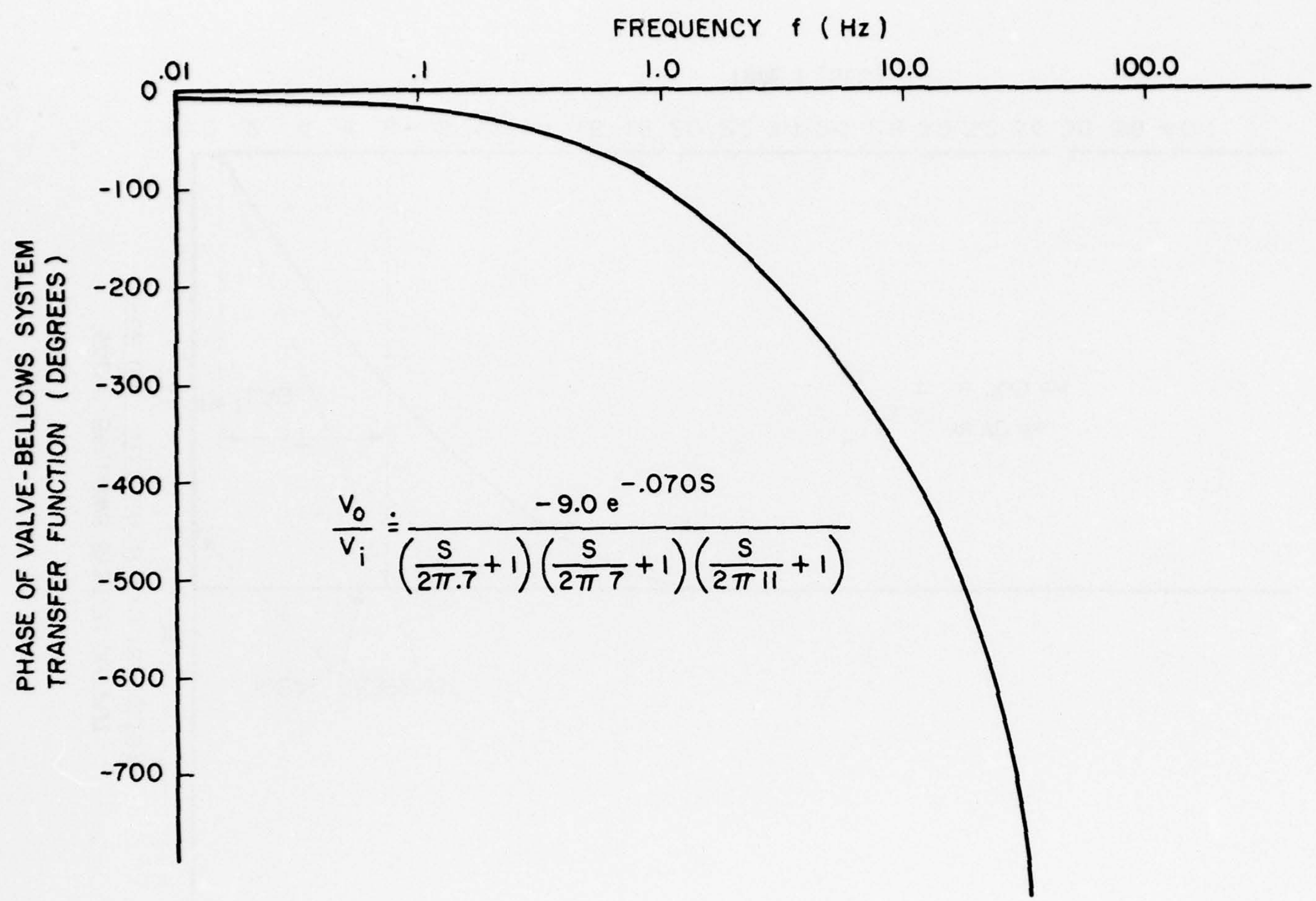


Figure 10. **Phase response of open-loop valve-bellows system.**

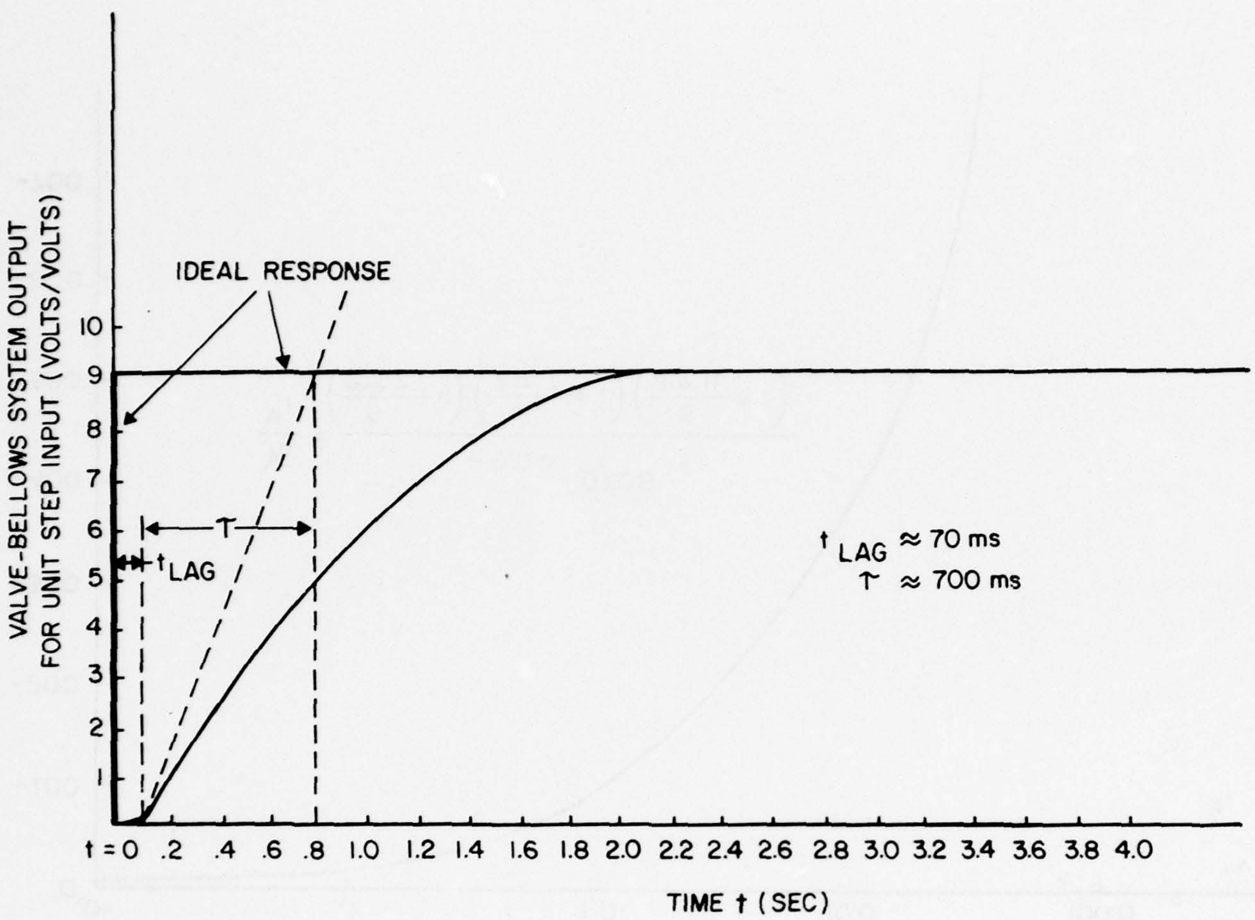


Figure 11. **Response and rise time characteristics of the open-loop valve-bellows system.**

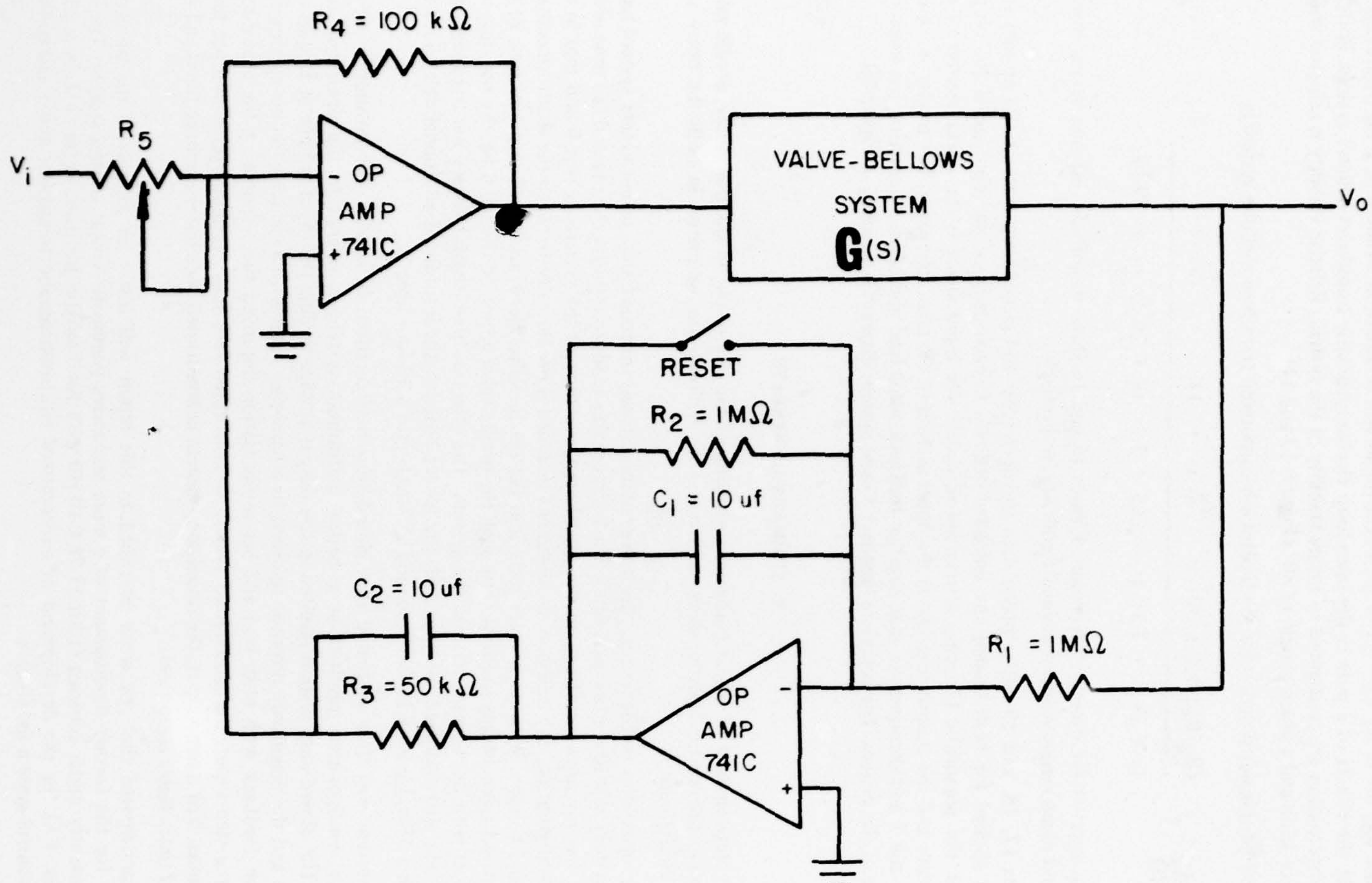


Figure 12. **Schematic of experimental closed-loop G-seat system.**

The $(s R_2 C_1 + 1)$ factor in the denominator of equation 3 functions as lead compensation to decrease phase lag; the $(s R_3 C_2 + 1)$ factor in the numerator of equation 3 functions as lag compensation to cancel out the effects of a pole in the open-loop electropneumatic transducer-bellows system. Both lag and lead compensation are configured to insure stability of the system. Relative stability is achieved with a gain margin of 12db and a phase margin of 80° (Figures 13 and 14).

The overall transfer function for the feedback-incorporated transducer-bellows system is:

$$\frac{Vo(s)}{Vi(s)} = \frac{(R_4/R_5)\ 1.2 \times 10^5\ e^{-.770s}\ (s + .1)}{(s + j3.5 + 2.3)\ (s - j3.5 + 2.3)\ (s + 24.2)\ (s + 89.1)} \tag{4}$$

where R_5 is selected for overall system gain. Figures 15 and 16 show magnitude response versus angular frequency and phase response versus angular frequency, respectively.

Figures 17, 18, and 19 are response data for open-loop and closed-loop systems. Ramp and step inputs were applied for both loaded and unloaded bellows. In each instance the input signal and output responses of the pneumatic G-cueing system are recorded; the input signal is the lower section of the recording paper and the output response is the upper section of the recording paper. The results are shown in Tables 2 and 3 and demonstrate that negative feedback using lead and lag compensation has improved the response of the system. The complete feedback G-seat system diagram is depicted in Figure 20.

V. SUMMARY OF RESULTS

A complete channel of G-seat hardware consisting of the electro-pneumatic transducer, needle valve, flexible tubing, pneumatic booster relay, and metal air bellows was evaluated in both the open- and closed-loop configuration.

In the open-loop configuration, the valve-bellows closely matched the current G-seat system hardware. The system acts like a low-pass filter. The booster relay tends to improve the rise and fall time of the bellows but has no apparent effect on the initial response time of the system. It was found that in the open-loop configuration, the optimum arrangement included a needle valve between the electropneumatic transducer and bellows. With no booster relay and the needle valve bleed, the initial response time of the system improved from 140ms to 90ms. Although the needle valve improved the fall time, the rise time was not as good as with the booster relay in the system. The effect of hose length between the transducer and the bellows was also evaluated. As expected, the longer hose lengths introduced additional delay into the system, with a 35ms lag for a 15-foot hose and a 75ms lag for a 43-foot hose.

The system was then evaluated in a closed-loop configuration. In general, the position feedback bellows-valve configuration resulted in a better performing system compared to the open-loop configuration. The closed-loop system resulted in the output voltage leading the input voltage at frequencies below 5 Hz and the magnitude response resulting in a band-pass filter with a resonant frequency around 4 Hz. Negative feedback with both lead and lag compensation improved the response of the closed-loop system. For a step input, the closed-loop system demonstrated 20% faster response times and ten times faster rise times. For a ramp input, the closed-loop system demonstrated 30% faster response times and one and one-half times faster ramp rates.

It is anticipated that the work described in this report will foster an interest in the simulator community for the further development of a more responsive pneumatic G-seat control system. The Air Force is currently under contract (F33657-78-C-0119) with the Franklin Institute Research Laboratories (Philadelphia, PA) for the development of an improved electropneumatic transducer and a closed-loop pneumatic control system for G-seats.

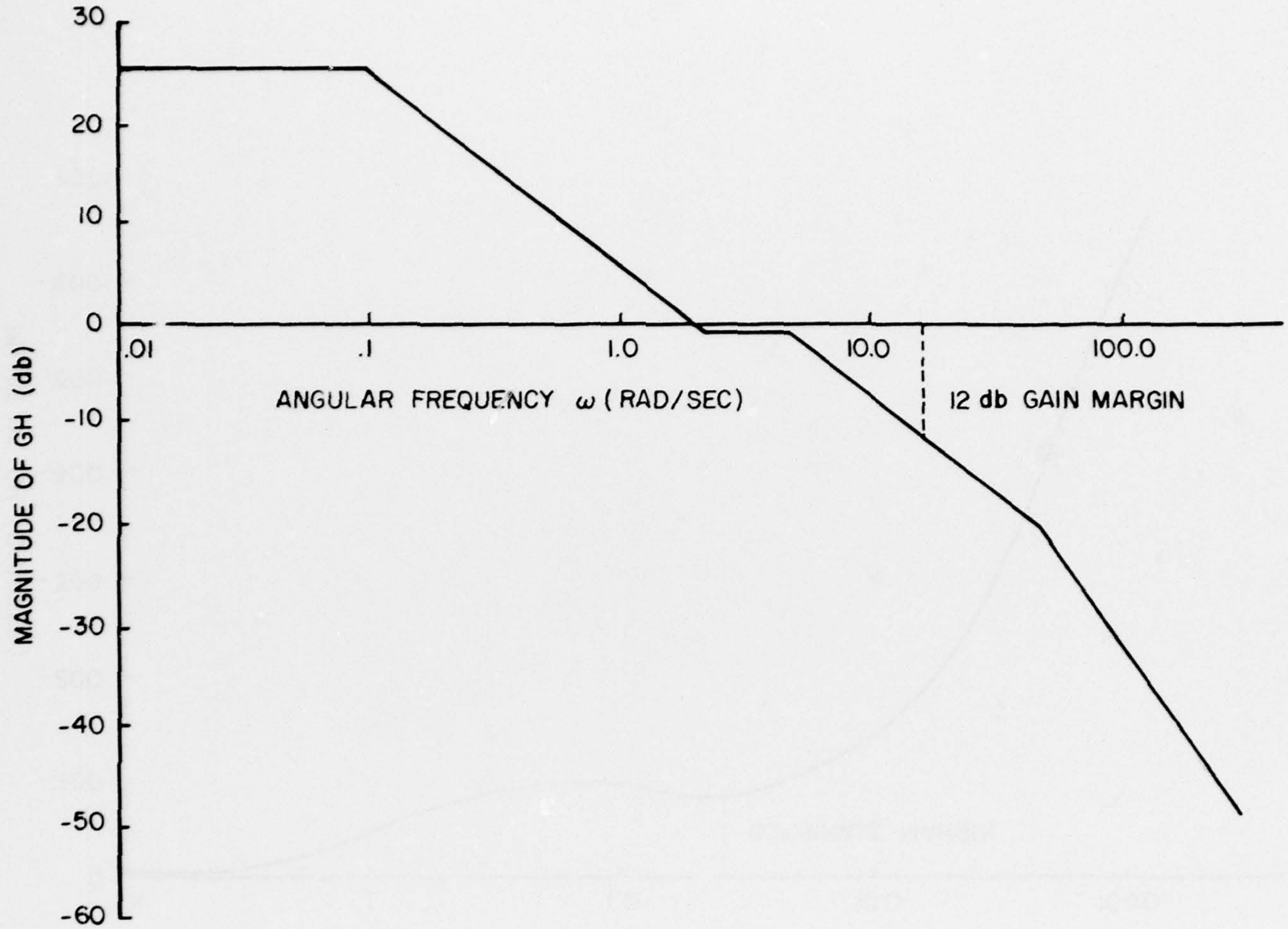


Figure 13. **Magnitude response of compensated valve-bellows.**

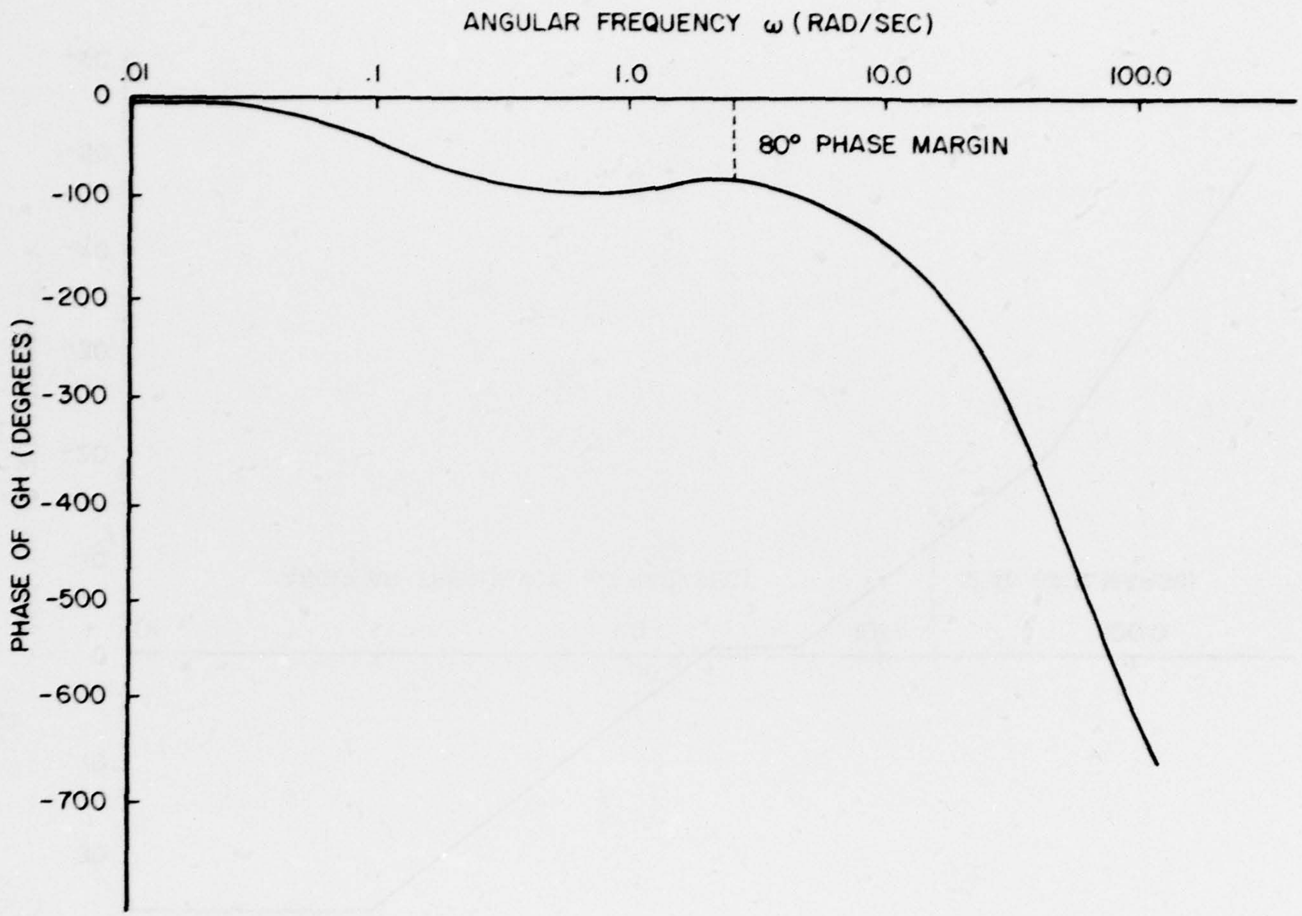


Figure 14. **Phase response of compensated valve-bellows.**

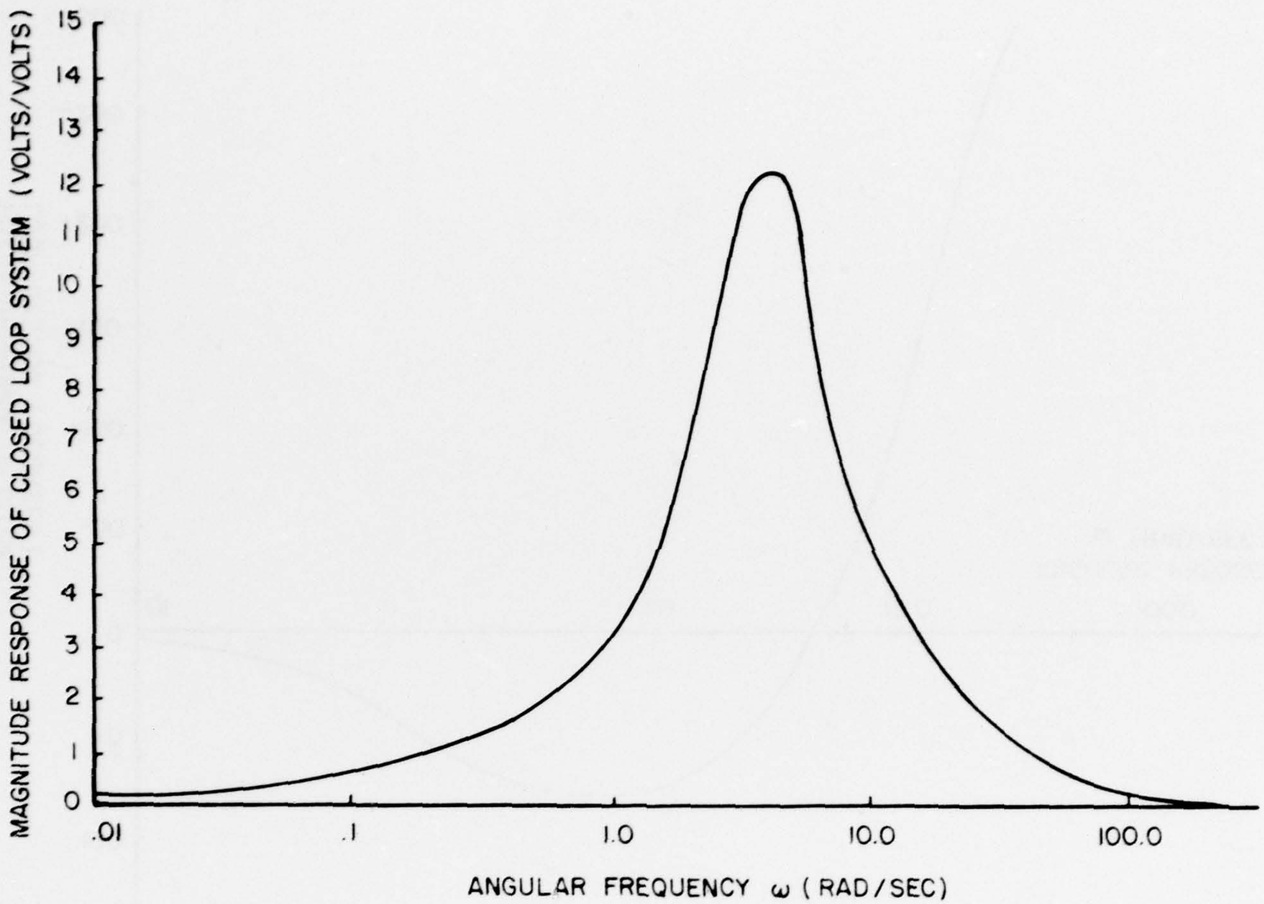


Figure 15. **Magnitude response of closed-loop G-seat system.**

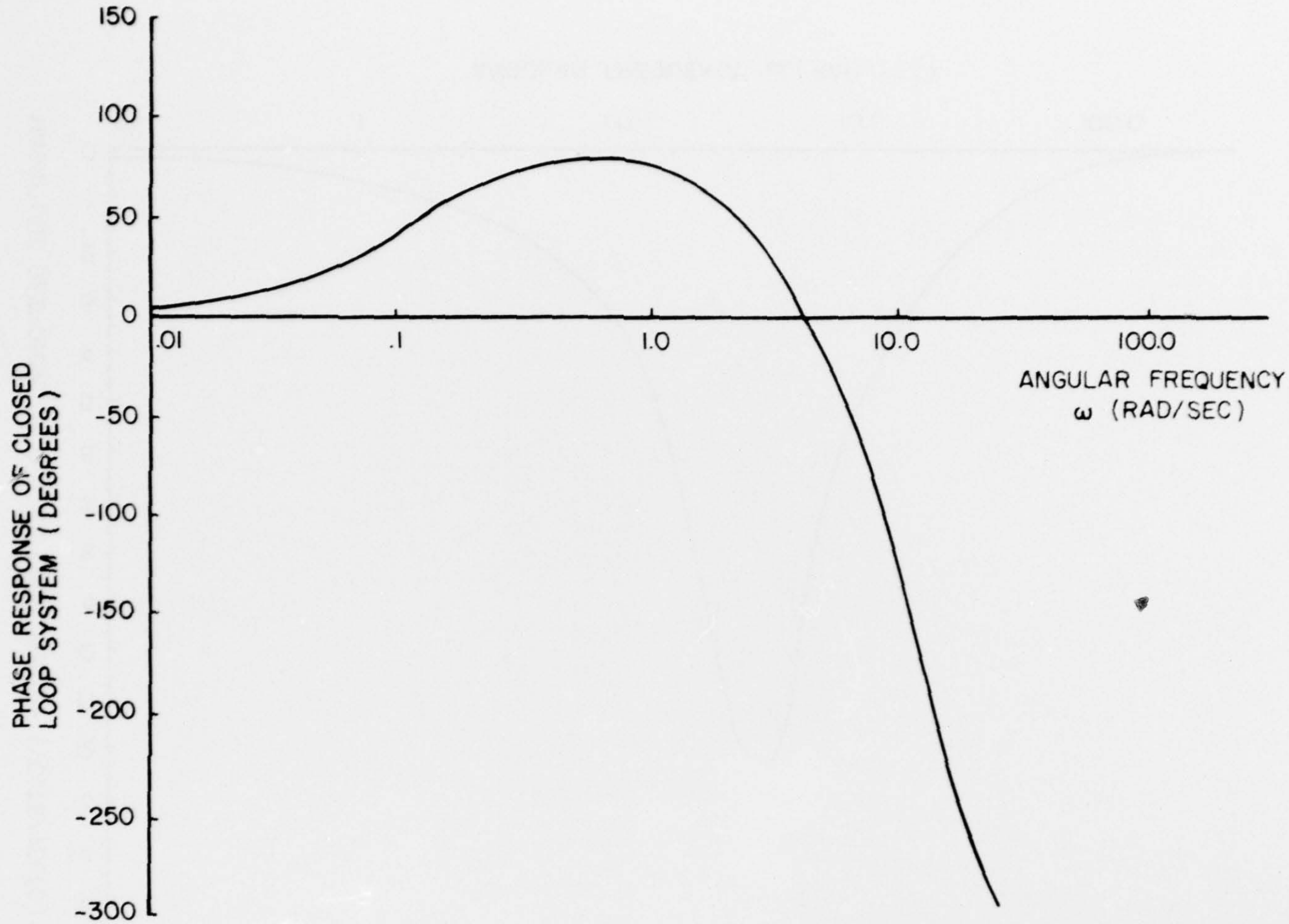
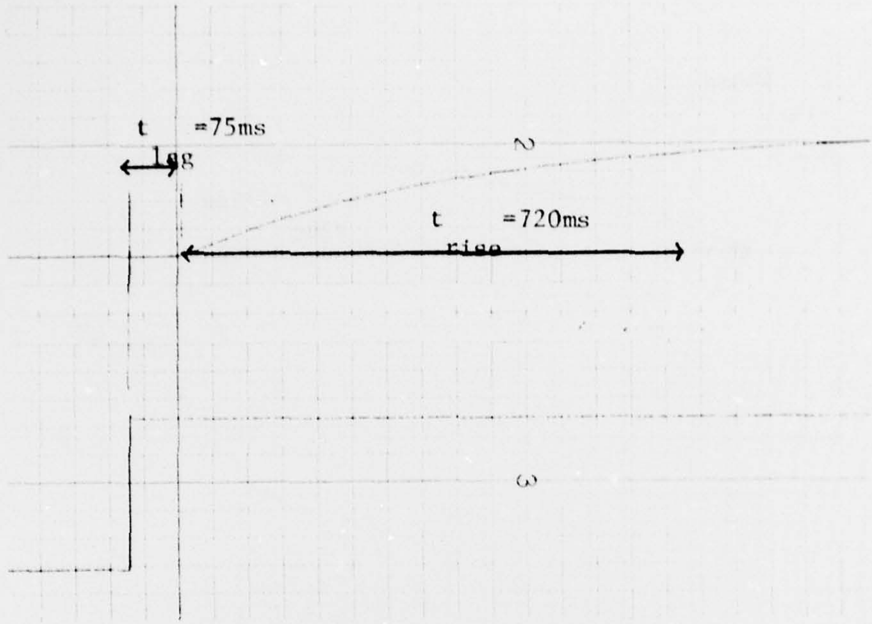
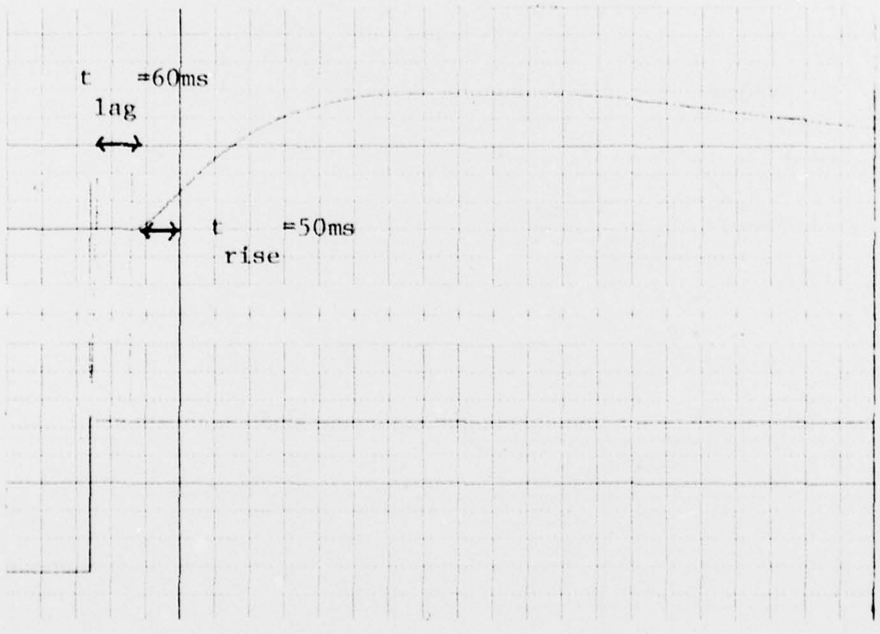


Figure 16. **Phase response of closed-loop G-seat system.**

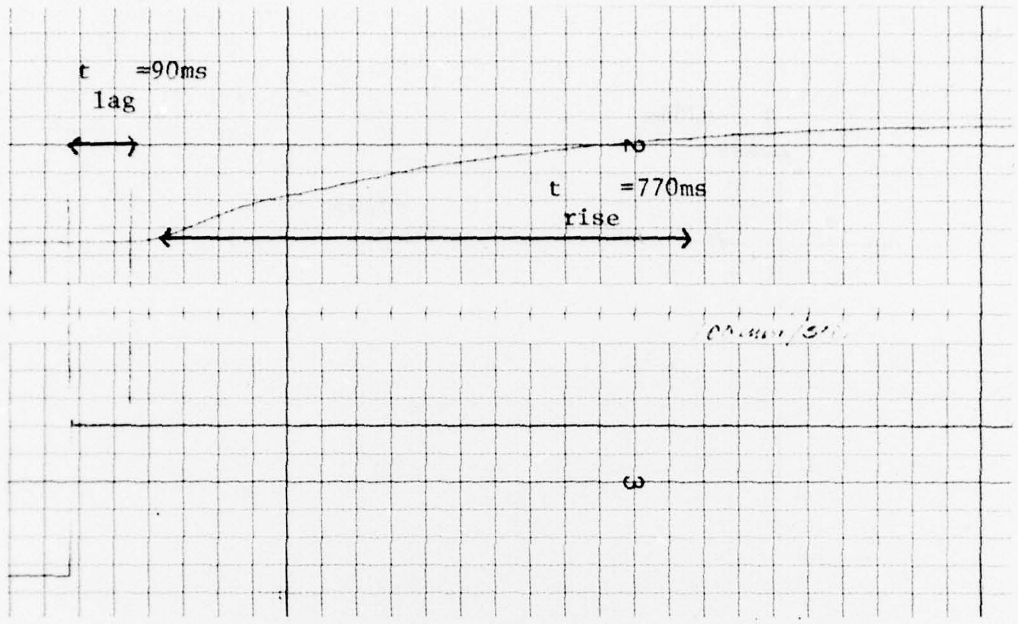


Open-Loop System Response with Step Input
(No weight, 43 foot hose)

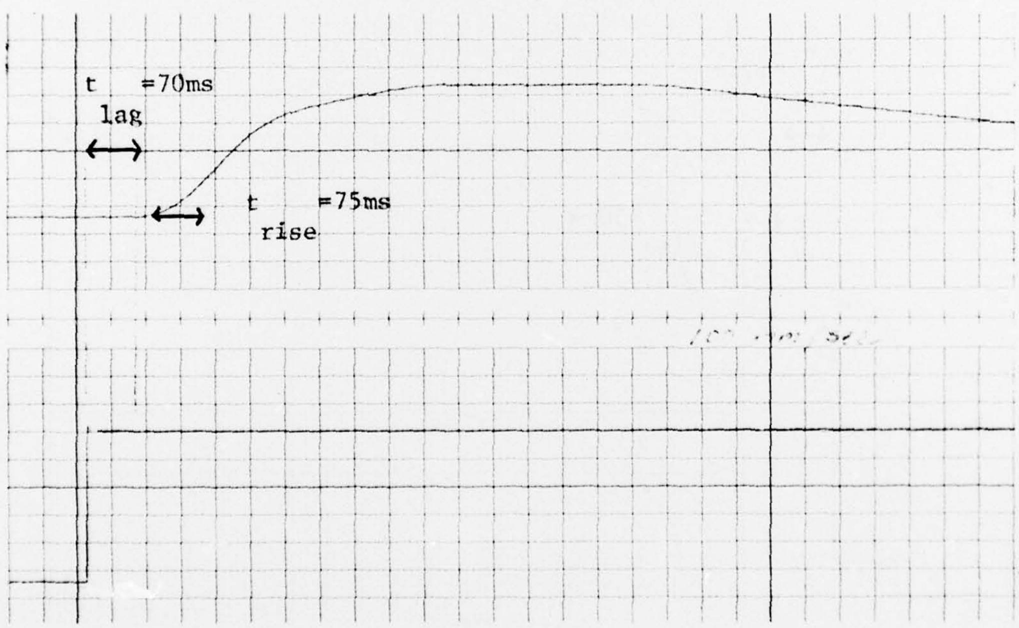


Closed-Loop System with Step Input
(No weight, 43 foot hose)

Figure 17. **Open and closed-loop system response to step input (no weight).**

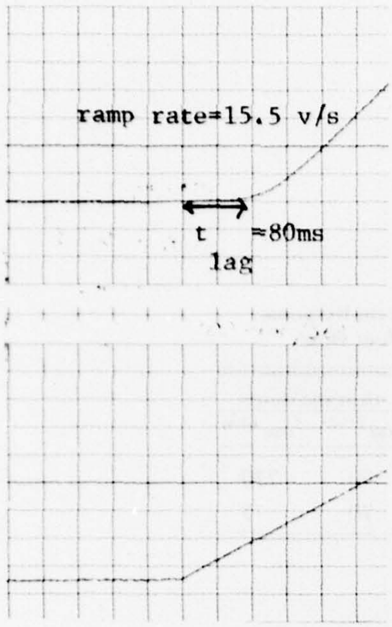


Open-Loop System Response with Step Input
(10-pound weight, 43 foot hose)

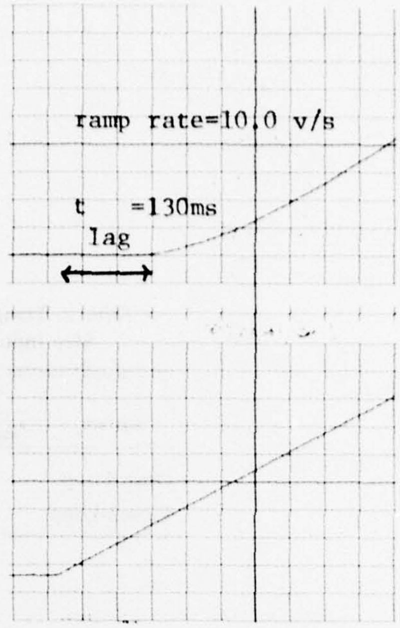


Closed-Loop System Response with Step Input
(10-pound weight, 43 foot hose)

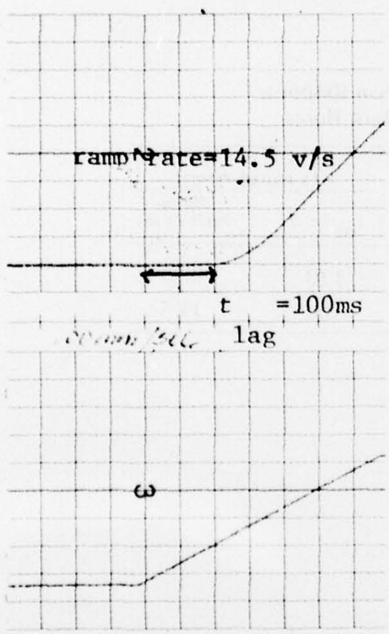
Figure 18. **Open and closed-loop system responde to step input (10-pound weight).**



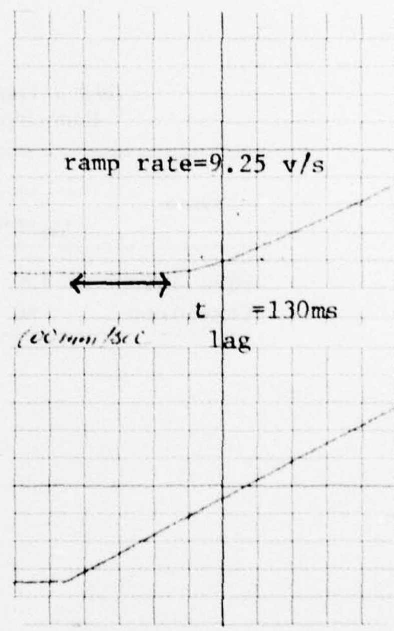
Closed-Loop Response
to Ramp Input
(No weight, 43 foot hose)



Open-Loop Response
to Ramp Input
(No weight, 43 foot hose)



Closed-Loop Response
to Ramp Input
(10-pound weight, 43 foot hose)



Open-Loop Response
to Ramp Input
(10-pound weight, 43 foot hose)

Figure 19. **Open and closed-loop system response to ramp input.**

Table 2. **Transducer Bellows System Response Step Input, Bleed Valve, 43 foot Hose**

System	No Weight		10-pound Weight	
	t_{lag} (ms)	t_{rise} (ms)	t_{lag} (ms)	t_{rise} (ms)
Open-Loop	75	720	90	770
Closed-Loop	60	50	70	75

Table 3. **Transducer Bellows System Response Ramp Input, Bleed Valve, 43 foot Hoses**

System	No Weight		10-pound Weight	
	t_{lag} (ms)	Ramp Rate (V/S)	t_{lag} (ms)	Ramp Rate (V/S)
Open-Loop	130	10	130	9.25
Closed-Loop	80	15.5	100	14.5

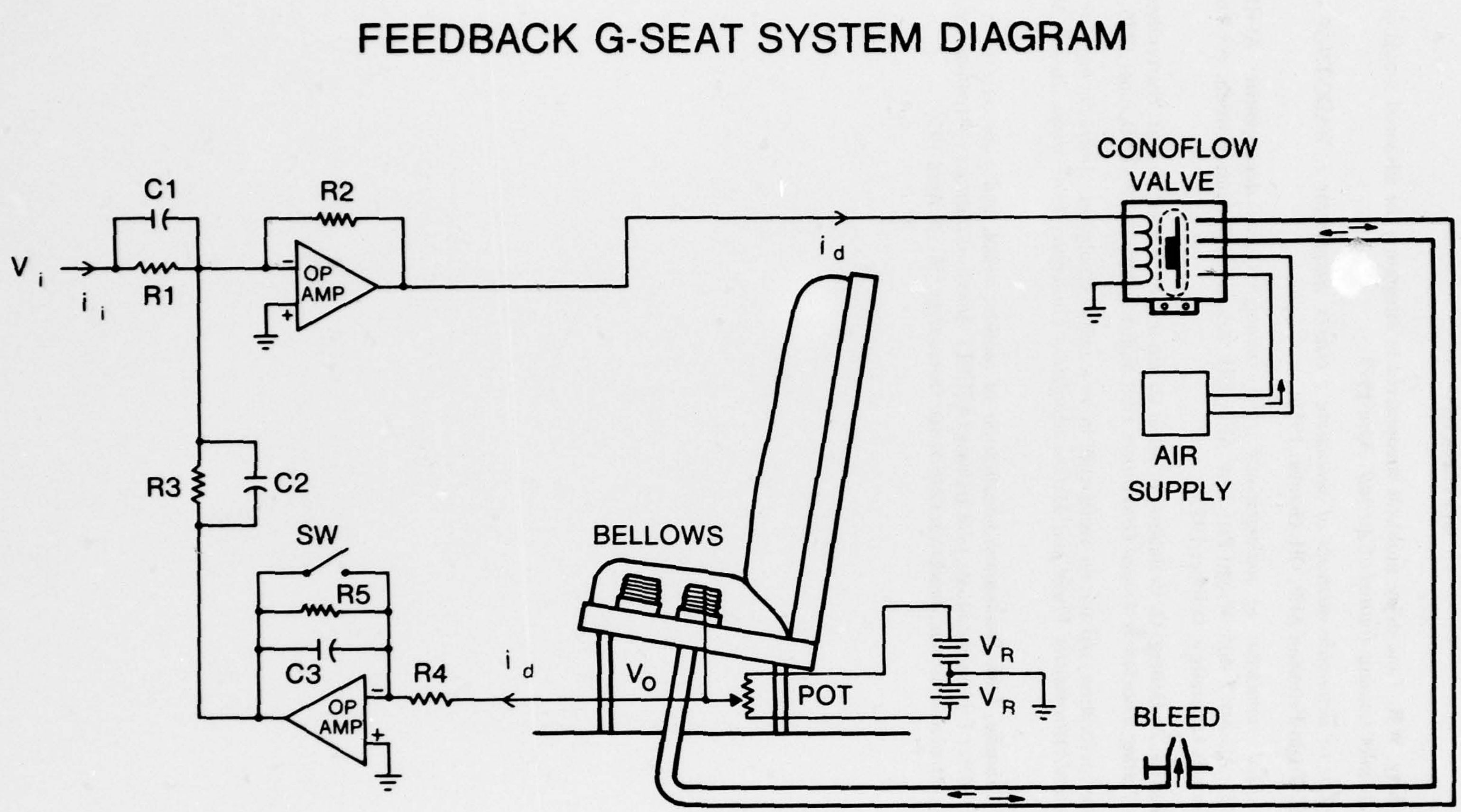


Figure 20. **Diagram of experimental feedback G-seat system.**

REFERENCES

Gum, D.R., & Albery, W.B. Time delay problems encountered in integrating the advanced simulator for undergraduate pilot training. *Journal of Aircraft*, April 1977.

Johnson, L.L. *Study to determine methods of simulating g effects, supplement 1.* WADC-TN-58-314, AD-211 849. Wright-Patterson AFB, OH: October 1958.

Kron, G.J. *Advanced simulation in undergraduate pilot training: G-seat development.* AFHRL-TR-75-59(III), AD-A017 468. Wright-Patterson AFB, OH: Advanced Systems Division, Air Force Human Resources Laboratory, October 1975.

MacFarland, B., Griffin, J., DeBerg, O. Evaluation of g-seat cueing in large bodied aircraft. *Proceedings of the Military Testing Association Annual Convention*, Gulf Shores, Alabama, 18–22 October 1976.

Stark, E.A. Motion perception and terrain visual cues in air combat simulation. *American Institute of Aeronautics and Astronautics Visual and Motion Simulation Conference Proceedings*, 26–28 April 1976.

Waters, B.K., & Grunzke, P.M. Preliminary investigation of motion, visual, and g-seat effects in the advanced simulator for undergraduate pilot training (ASUPT). *American Institute of Aeronautics and Astronautics Visual and Motion Simulation Conference Proceedings*, 26–28 April 1976.

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